Patents Form 1/77

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GB 0210886.8

The Patent Office

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NP9 1RH

1. Your reference	CTV/P100245GB
2. Patent application number *(The Patent Office will fill in this part)*	
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Zap Wireless Technologies Limited Downing Park Innovation Centre Swaffham Bulbeck Cambridge CB5 0NB
Patents ADP number *(if you know it)*	
If the applicant is a corporate body, give the country/state of its incorporation	UK
4. Title of the invention	Improvements relating to contact-less power transfer
5. Name of your agent *(if you have one)*	Harrison Goddard Foote
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Belgrave Hall Belgrave Street Leeds LS2 8DD
Patents ADP number *(if you know it)*	14571001

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	25
Claim *(s)*	5
Abstract	1
Drawing *(s)*	14

10. If you are also filing any of the following, state how many against each item.

Priority documents		
Translations of priority documents		
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*		
Request for preliminary examination and search *(Patents Form 9/77)*	1	
Request for substantive examination *(Patents Form 10/77)*		
Any other documents *(please specify)*	1	Cover letter, fee sheet

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 13/5/2002

12. Name and daytime telephone number of person to contact in the United Kingdom — Chris Vaughan — 0113 233 0100

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Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

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Patents Form 9/77

Patents Act 1977
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The Patent Office

Request for a preliminary examination and search

(See the notes on the back of this form)

The Patent Office

Cardiff Road
Newport
South Wales
NP9 1RH

1. Your reference

CTV/P100245GB

2. Patent application number
(If you know it)

3. Full name of the or of each applicant

Zap Wireless Technologies Limited

4. Is this request for:

a) A preliminary examination and search under Section 17(1) for an international application which has been searched in the international phase? *(see note (f))*

b) A preliminary examination and search under Section 17(1) for any other application?

(b)

c) A supplementary search under Section 17(8)?

(d) A search of a further invention under Section 17(6)?

(Answer this question by writing (a), (b), (c) or (d)).
If your answer is (d), identify the invention to be searched by referring to the claims *(see note (c))*.

5. Do you want any extra copies of any documents cited in the search report? *(see note (d))*

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If so, state how many and remember to pay the extra fee

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6. Signature

Date

13/5/2002

7. Name and daytime telephone number of person to contact in the United Kingdom

Chris Vaughan

0113 233 0100

IMPROVEMENTS RELATING TO CONTACT-LESS POWER TRANSFER

This invention relates to a new device and method for transferring power in a contact-less fashion.

Many of today's portable devices incorporate "secondary" power cells which can be recharged, saving the user the cost and inconvenience of regularly having to purchase new cells. Example devices include cellular telephones, laptop computers, the Palm 500 series of Personal Digital Assistants, electric shavers and electric toothbrushes. In some of these devices, it is possible to charge the cells via inductive coupling rather than direct electrical connection. Examples include the Braun Oral B Plak Control power toothbrush, the Panasonic Digital Cordless Phone Solution KX-PH15AL and the Panasonic multi-head men's shavers ES70/40 series.

Each of these devices typically has an adaptor or charger which takes power from mains electricity, a car cigarette lighter or other sources of power and converts it into a form suitable for charging the secondary cells. There are a number of problems associated with conventional means of powering or charging these devices:

- Both the characteristics of the cells within each device and the means of connecting to them vary considerably from manufacturer to manufacturer, and from device to device. Therefore users who own several such devices must also own several different adaptors. If users are going away on travel, they will have to bring their collection of chargers if they expect to use their devices during this time.

- These adaptors and chargers often require users to plug a connector into the device or to place the device into a stand causing inconvenience. If users fail to plug or place their device into a charger and it runs out of power, the device becomes useless and important data stored locally in the device might even be lost.

- In addition, most adaptors and chargers have to be plugged into mains sockets and hence if several are used together, they take up space in plug strips and create a messy and confusing tangle of wires.

- Besides the above problems with conventional methods of recharging devices, there are also practical problems associated with devices having an open electrical contact. For example, devices cannot be used in wet environments due to the possibility of corroding or shorting out the contacts and also they cannot be used in flammable gaseous environments due to the possibility of creating electrical sparks.

Chargers which use inductive charging remove the need to have open electrical contacts hence allowing the adaptor and device to be sealed and used in wet environments (for example the electric toothbrush as mentioned above is designed to be used in a bathroom). However such chargers still suffer from all other problems as described above. For example, the devices still need to be placed accurately into a charger such that the device and the charger are in a predefined relative position (See Figures 1a and 1b). The adaptors are still only designed specifically for a certain make and model of device and are still only capable of charging one device at a time. As a result, users still need to possess and manage a collection of different adaptors.

Universal chargers (such as the Maha MH-C777 Plus Universal charger) also exist such that battery packs of different shapes and characteristics can be removed from the device and charged using a single device. Whilst these universal chargers eliminate the need for having different chargers for different devices, they create even more inconvenience for the user in the sense that the battery packs first need to be removed, then the charger needs to be adjusted and the battery pack needs to be accurately positioned in or relative to the charger. In addition, time must be spent to determine the correct pair of battery pack metal contacts which the charger must use.

It is also known that patent US5959433: "Universal Inductive Battery Charger System" describes a non-contact battery charging system. The battery charger

described includes a single charging coil which creates magnetic flux lines which will induce an electrical current in a battery pack which may belong to cellular phones or laptop computers.

It is also known that patent US4873677: "Charging Apparatus for an Electronic Device" describes an apparatus for charging an electronic device which includes a pair of coils. This pair of coils is designed to operate in anti-phase such that magnetic flux lines are coupled from one coil to the other. An electronic device such as a watch can be placed on these two coils to receive power.

It is also known that patent US5952814: "Induction charging apparatus and an electronic device" describes an induction charger for charging a rechargeable battery. The shape of the external casing of the electronic device matches the internal shape of the charger thus allowing for accurate alignment of the primary and secondary coils.

To overcome the problems associated with axial alignment of primary and secondary units of an inductive power transfer system, one might propose that an obvious means is to use a simple inductive power transfer system whereby the base unit is capable of emitting an electromagnetic field over a large area (See Figure 2a). Users can simply place one or more devices to be recharged within range of the charger, with no requirement to place them accurately. For example this primary unit may consist of a coil encircling a large area. When a current flows through the coil, a large electromagnetic field is created and devices can be placed anywhere within this area. Although theoretically feasible, this method suffers from a number of drawbacks. Firstly, the intensity of electromagnetic emissions is governed by regulatory limits. This means that this method can only support power transfer at a low rate. In addition, there are many objects that can be affected by the presence of a large magnetic field. For example, data stored on credit cards maybe destroyed and objects made of metal will have induced therein eddy currents generating undesired heating effects.

To avoid the generation of large magnetic fields, one might suggest using an array of coils (See Figure 3) whereby only the coils needed are activated. This method is described in a paper published in the Journal of the Magnetics Society of Japan titled "Coil Shape in a Desk-type Contactless Power Station System" (29th Nov 2001). In an embodiment of the multiple-coil concept, a sensing mechanism senses the relative. location of the secondary unit relative to the primary unit. A control system then activates the appropriate coils to deliver power to the secondary unit in a localised fashion. Although this method provides a solution to the problems previously listed, it does so in a complicated and costly way. The degree to which the primary field can be localised is limited by the number of coils and hence the number of driving circuits used (i.e. the "resolution" of the primary unit). The cost associated a multiple-coil system would severely limit the commercial applications of this concept. Non-uniform field distribution is also a drawback. When all the coils are activated in the primary unit, they sum to an equivalent of a large coil, the magnetic field distribution of which is seen to exhibit a minimum at the centre of the coil.

None of the prior art devices can satisfactorily address all of the problems that have been described. It would be convenient to have a solution which is capable of transferring power to portable devices with all of the following features and is cost effective to implement:

- Universality: a single base unit which can supply power to different devices with different power requirements thereby eliminating the need for a collection of different adaptors and chargers;
- Convenience: a single base unit which allows devices to be placed anywhere within an active vicinity thereby eliminating the need for plugging-in or placing devices accurately relative to an adaptor or charger;
- Multiple-load: a single base unit that can supply power to a number of different devices with different power requirements at the same time;
- Flexibility for use in different environments: a single base unit that can supply power to devices such that no direct electrical contact is required

thereby allowing for devices and the base unit itself to be used in wet, gaseous, clean and other atypical environments

- Low electromagnetic emissions: a base unit that can deliver power in a manner that will minimize the intensity and size of the magnetic field generated

According to a first aspect of the present invention, there is provided a system for transferring power without requiring direct electrical conductive contacts, the system comprising:

i) a primary unit having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to the plane of the surface within the active area; and

ii) at least one secondary unit including at least one conductor wound about a core;

wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in at least one orientation thereof substantially parallel to the surface of the primary unit in the active area, such that when the at least one secondary unit is placed on or in proximity to the active area in a predetermined orientation, the electromagnetic field induces a current in the at least one conductor of the at least one secondary unit.

According to a second aspect of the present invention, there is provided a primary unit device for transferring power in a non-conductive manner to at least one secondary unit including at least one conductor wound about a core, the primary unit device having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a

current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to a plane of the surface within the active area., and wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in at least one. orientation thereof substantially parallel to the surface of the primary unit in the active area.

According to a third aspect of the present invention, there is provided a method of transferring power in a non-conductive manner from a primary unit to a secondary unit, the primary unit having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to the plane of the surface within the active area, and the secondary unit having at least one conductor wound about a core, wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in at least one orientation thereof substantially parallel to the surface of the primary unit within the active area and wherein flux lines of the electromagnetic field pass through the core of the secondary unit when this is placed on or in proximity to the active area as a result of the core offering a path of least reluctance.

According to a fourth aspect of the present invention, there is provided a secondary unit for use with the system, device or method of the first, second or third aspects, the secondary unit including at least one conductor wound about a core and having a substantially flat form factor.

The at least one conductor in the primary unit may be a coil, for example in the form of a length of wire or a printed strip, or may be in the form of a conductive plate of appropriate configuration. A preferred material is copper, although other conductive materials may be used as appropriate.

The core in the secondary unit is preferably a high magnetic permeability core. The relative permeability of this core is preferably at least 100, even more preferably at least 500, and most preferably at least 1000, with magnitudes of at least 10,000 or 100,000 being particularly advantageous.

Preferably, the active area of the primary unit is large enough to accommodate the core of the secondary unit in a plurality of orientations thereof. In a particularly preferred embodiment, the active area is large enough to accommodate the core of the secondary unit in any orientation thereof. In this way, power transfer from the primary unit to the secondary unit may be achieved without having to align the core of the secondary unit in any particular direction when placing the secondary unit on the surface of the primary unit.

The substantially laminar surface of the primary unit may be substantially planar, or may be curved or otherwise configured to fit into a predetermined space, such as a glove compartment of a car dashboard or the like.

The secondary unit may adopt a substantially flat form factor with a core thickness of 2mm or less. Using a material such as one or more amorphous metal sheets, it is possible to have core thickness down to 1mm or less for applications where size and weight is important. See Figure 7a.

According to a fifth aspect of the present invention, there is provided a system for transferring power in a contact-less manner consisting of:

- a primary unit consisting of at least one electrically independent coil whereby each coil features at least one active area whereby two or more conductors are substantially distributed over this area in such a fashion that it is possible for a secondary unit to be placed in proximity to a part of this active area where the net instantaneous current flow in a particular direction is substantially non-zero;

- at least one secondary unit consisting of conductors wound around a high permeability core in such a fashion that it is possible for it to be placed in proximity to an area of the surface of the primary unit where the net instantaneous current flow is substantially non-zero;

whereby the at least one secondary unit is capable of receiving power by means of electromagnetic induction when the central axis of the winding is in proximity to the active area of the primary, is substantially not perpendicular to the plane of the active area of primary unit and is substantially not parallel to the conductors in the active area of at least one of the coils of the primary.

The proposed invention is a significant departure from the design of conventional inductive power transfer systems. The difference between conventional systems and the proposed system is best illustrated by looking at their respective magnetic flux line patterns. (See Figure 2a and 4)

- Conventional System: In a conventional system (See Figure 2a), there is typically a planar primary coil which generates a magnetic field with flux lines coming out of the plane in a perpendicular fashion. The secondary unit is typically a round or square coil that encircles some or all of these flux lines.

- Proposed system: In the proposed system, the magnetic field travels horizontally across the surface of the plane (see figure 4) instead of directly out of the plane as illustrated in Figure 2a. The secondary unit hence is an elongated winding wound around a magnetic core. See Figure 7a and 7b. When the secondary unit is placed on the primary unit, the flux lines would be attracted to travel through the magnetic core of the secondary unit because it is the lowest reluctance path. This causes the secondary unit and the primary unit to be coupled effectively. The secondary core and winding maybe substantially flattened to form a very thin unit.

In describing the invention, specific terminology will be resorted to for the sake of clarity. However, it is not intended that the invention be limited to the specific terms so selected and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

It is to be understood that the term "active area" used in this patent refers to the area of the primary coil or an area formed by a combination of primary coils where the secondary unit can couple flux effectively. Some embodiments of this are shown in Figures 6a to 6e and 9c as component **740**. A feature of an "active area" is a distribution of conductors over a significant area of the primary magnetic unit configured such that it is possible for the primary coil or coils to be driven to achieve an instantaneous net flow of flux in one direction. A primary unit may have more than one active area. One active area is distinct from another active area when flux cannot be effectively coupled by the secondary unit (shown in Figure 7a) in any rotation at the boundary.

It is to be understood that the term "coil" used in this patent refers to all configurations of copper which features an active area as described above. This includes windings of copper wire or printed copper tracks or a plane of copper as shown in Figure 8e.

This patent refers to the rotation of a secondary unit in several places. It is to be clarified here that if a secondary unit is rotated, the axis of rotation being referred to is the one perpendicular to the plane of the active area.

This radical change in design overcomes a number of drawbacks of conventional systems. The benefits of the proposed invention include:

- No need for accurate alignment: The secondary unit can be placed anywhere on the active area of the primary unit;

- Uniform coupling: In the proposed invention, the coupling between the primary and secondary unit is much more uniform over the active area compared to a conventional primary and secondary coil. In a conventional large coil system (see Figure 2a), the field strength dips to a minimum at the centre of the coil, in the plane of the coil. This implies that if sufficient. power is to be effectively transferred at the centre, the field strength at the minimum has to be above a certain threshold. The field strength at the maximum will then be excessively higher than the required threshold and this may cause undesirable effects.

- Universality: a number of different secondary units can be placed anywhere on the primary unit to receive power simultaneously;

- Increased coupling coefficiency: High permeability magnetic material present in the secondary unit increases the induced flux significantly by offering a low reluctance path. This can significantly increase the power transfer.

- Desirable form factor for secondary unit: The geometry of the system allows thin sheets of magnetic material (such as amorphous metal ribbons) to be used. This means that secondary units can have the form factor of a thin sheet, making it suitable to be incorporated at the back of mobile phones and other electronic devices. If magnetic material was to be used in the centre of conventional coils, it is likely to increase the bulkiness of whole system.

- Minimised field leakage: When one or more secondary units are present in the active area of the primary unit, it is possible to use magnetic material in such a way that more than half of the magnetic circuit is low reluctance magnetic material (see figure 4e). This means that more flux flows for a given magneto-motive force (mmf). As the induced voltage is proportional to the rate of change of flux linked, this will increase the power transfer to the secondary. The fewer and shorter the air gaps are in the magnetic circuit, the

less the field will fringe, the closer the flux is kept to the surface of the primary unit and hence leakage is minimized.

- Cost effectiveness: Unlike the multiple-coil design, this solution requires a much simpler control system and fewer components.

The primary unit typically consists of the following components. (See Figure 5)

- Power supply: This power supply converts mains voltage into a lower voltage dc supply. This is typically a conventional transformer or a switch-mode power supply;

- Control unit: The control unit serves the function of maintaining the resonance of the circuit given that the inductance of the magnetic component changes with the presence of secondary units. To enable this function, the control unit may be coupled to a sensing unit which feeds back the current status of the circuit. It may also be coupled to a library of capacitors which may be switched in and out as required. If the magnetic unit requires more than one driving circuit, the control unit may also coordinate the parameters such as the phase difference or on/off times of different driving circuits such that the desired effect is achieved. It is also possible for the Q of the system to be designed to function over a range of inductances such that a need the above control system is eliminated;

- Driving circuit: The driving unit is controlled by the control unit and drives a changing current through the magnetic unit or a component of the magnetic unit. More than one driving circuit may be present depending on the number of independent components in the magnetic unit;

- Magnetic unit: The magnetic unit uses current supplied from the driving circuits to generate magnetic fields of pre-defined shapes and intensities. The exact configuration of the magnetic unit defines the shape and intensity of the

field generated. The magnetic unit is likely to consist of magnetic material to act as flux guides and also one or more independently driven components (windings), together forming the active area. A number of embodiment designs are possible and this is shown in Figures 6.

- Sensing unit: The sensing unit retrieves and sends relevant data to the control unit for interpretation.

The secondary unit typically consists of the following components, as shown in Figure 5.

- Magnetic unit: the magnetic unit converts the energy stored in the magnetic field generated by the primary unit back into electrical energy. This is typically implemented by means of a winding wound around a highly permeable magnetic core. The largest dimension of the core typically coincides with the central axis of the winding.

- Conversion unit: the conversion unit converts the fluctuating current received from the magnetic unit into a form that is useful to the device that it is coupled to. For example, the conversion unit may convert the fluctuating current into an unregulated dc supply by means of a full-wave bridge rectifier and smoothing capacitor. In other cases, the conversion unit may be coupled to a heating element or a battery charger. There is also typically a capacitor present either in parallel or in series with the magnetic unit to form a resonant circuit at the operating frequency of the primary unit.

In typical operation, one or more secondary units are placed on top of the active area of the primary unit. The flux flows through the core of the secondary units present and current is induced. Depending on the configuration of the primary magnetic unit, the rotation of the secondary unit may affect the amount of flux coupled.

The primary unit

The primary unit may exist in many different forms, for example:

- As a flat platform which can sit on top of tables and other flat surfaces;
- Built in to furniture such as desks , tables, counters, chairs such that the base unit may not be visible;
- As part of an enclosure such as a drawer, a box, a glove compartment of a car, the container of power tools;
- As a flat platform which can be attached to a wall and used vertically;

The primary unit may be powered from different sources, for example:

- Mains power
- Batteries
- Fuel Cells
- Solar Panel
- Human power

The primary unit may be small enough such that only one secondary unit may be accommodated within the active area, or may be large enough to accommodate many secondary units simultaneously.

The magnetic unit of the primary unit may be driven at mains frequency (50Hz or 60Hz) or at some higher frequency to the secondary units.

The sensing unit of the primary unit may sense the presence of secondary units, the number of secondary units present and even the presence of other magnetic material which is not part of a secondary unit. This information may be used to control the current being delivered to the magnetic unit of the primary unit.

The primary unit and/or the secondary unit may be substantially waterproof or explosion proof.

The primary unit and/or the secondary unit may be hermetically sealed to standards such as IP66.

The primary unit may incorporate visual indicators (for example, but not limited to, light emitting devices, such as light emitting diodes, electrophosphorescent displays, light emitting polymers, or light reflecting devices, such as liquid crystal displays or MITs electronic paper) to indicate the current state of the primary unit, the presence of secondary units or the number of secondary units present or any combination of the above.

The primary coil

The primary coil as referred to in this invention includes all configurations of conductors where:

- The conductors are substantially distributed in the plane and;
- Substantial areas of the plane exist where there is a non-zero net instantaneous current flow. These are areas on which, given the correct orientation, the secondary units will couple effectively and receive power. (See Figure 6)
- The conductors are capable of generating an electromagnetic field where the field lines are substantially parallel to a substantial area of the plane.

Figure 6 illustrates some possibilities for such a coil. Although most of the configurations are in fact coil windings, it is to be appreciated that the same effect can also be achieved with conductor planes which are not typically considered to be coils (See Figure 6e). These drawings are typical examples and are non-exhaustive. These coils may be used in combination such that the secondary unit can couple effectively in all rotations whilst on the active area of the primary unit.

Magnetic Material

It is possible to use magnetic materials in the primary unit to enhance performance.

- Magnetic material may be placed below the active area such that there is also a low reluctance path on the underside of the conductors for the flux to

complete its path. According to theory, an analogy can be drawn between magnetic circuits and electrical circuits. Voltage is analogous to magneto-motive force (mmf), resistance is analogous to reluctance and current is analogous to flux. From this, it can be seen that for a given mmf, flux flow will increase if the reluctance of the path is decreased. By providing magnetic material to the underside of the active area, we are essentially decreasing the reluctance of the magnetic circuit. This substantially increases the flux linked by the secondary unit and ultimately increases the power transferred. Figure 4e illustrates a sheet of magnetic material placed underneath the active area and the resulting magnetic circuit.

- Magnetic material may also be placed above the active area and below the secondary units to act as a flux guide. This flux guide performs two functions: Firstly, it decreases the reluctance of the whole magnetic circuit is further decreased allowing more flux will flow. Secondly, it provides a low reluctance path along the top surface of the active area so the flux lines will flow through these flux guides in favour of flowing through the air. Hence this has the effect of containing the field close to the surface of the primary unit instead of in the air. The magnetic material used for flux guides may be strategically chosen to have different magnetic properties to the magnetic core of the secondary unit. For example, a material with lower permeability and higher saturation may be chosen. High saturation means that the material can carry more flux and the lower permeability means that when a secondary unit is in proximity, a significant amount of flux would then choose to travel through the secondary unit in favour of the flux guide. (See Figure 8)

- In some primary magnetic unit configurations, there may be conductors present that do not form part of the active power transfer area, such as the component marked **745** in Figure 6a and 6b. In such cases, one may wish to use magnetic material to shield the effects of these conductors.

- Examples of some materials which may be used include but is not limited to: amorphous metal (metallic glass alloys), mesh of wires made of magnetic material, ferrite cores, mumetal.

The Secondary unit

The secondary unit may take a variety of shapes and forms. Generally, in order for good flux linkage, the central axis of the winding should be substantially non-perpendicular to the active area.

- The secondary unit may be in the shape of a flattened winding. (See Figure 7a) The magnetic core inside can consist of sheets of magnetic material such as amorphous metals. This geometry allows the secondary unit to be incorporated at the back of electronic devices such as mobile phones, personal digital assistants and laptops without adding bulk to the device.
- The secondary unit may be in the shape of a long cylinder. A long cylindrical core could be wound with conductors (See Figure 7b).
- The secondary unit may be a standard-sized (AA, AAA, C, D) rechargeable battery cell with magnetic material wrapped around the cylinder and windings around the cylindrical body.
- The secondary unit may be a combination of two or more of the above. The above embodiments may even be combined with a conventional coil

The following non-exhaustive list illustrates some examples of objects that can be coupled to a secondary unit to receive power. Possibilities are not limited to those described below:

- A mobile communication device, for example a radio, mobile telephone or walkie-talkie;
- A portable computing device, for example a personal digital assistant or palmtop or laptop computer;
- Portable entertainment devices, for example a music player, game console or toy;
- Personal care items, for example a toothbrush, shaver, hair curler, hair rollers;
- A portable imaging device, for example video recorder or camera;

- Containers of contents that may require heating, for example coffee mugs, plates, cooking pots, nail-polish and cosmetic containers;
- Consumer devices, for example torches, clocks and fans;
- A battery-pack for insertion into any of the above;
- A standard-sized battery cell;

Rotating magnetic dipole

In the coils such as those in Figure 6, 9a and 9b, the secondary units will generally only couple effectively when the windings are placed substantially parallel to the direction of net current flow in the primary as shown by the arrow **1**. In some applications, one might require a primary unit which will transfer power effectively to secondary units regardless of their rotation as long as:

- the central axis of the secondary is not perpendicular to the plane and;
- the secondary unit is in close proximity to the primary unit

To enable this, it is possible to have two coils one positioned on top of the other, the second coil capable of generating a net current flow substantially perpendicular to the direction of the first coil at any point in the active area of the primary unit. These two coils may be driven alternately such that each is activated for a certain period of time. Another possibility is to drive the two coils in quadrature such that a rotating magnetic dipole is generated in the plane. This is illustrated in Figure 9. This is also possible with other combinations of coil configurations.

Resonant circuits

It is state of the art to drive coils using parallel or series resonant circuits. In series resonant circuits for example, the impedance of the coil and the capacitor are equal and opposite at resonance, hence the total impedance of the circuit is minimised and a maximum current flows through the primary coil. The secondary unit is typically also tuned to the operating frequency to maximise the induced voltage or current.

In some systems like the electric toothbrush, it is common to have a circuit which is detuned when the secondary unit is not present and tuned when the secondary unit is

in place. The magnetic material present in the secondary unit shifts the self-inductance of the primary unit and brings the circuit into resonance. In other systems like passive radio tags, there is no magnetic material in the secondary and hence does not affect the resonant frequency of the system. These tags are also typically small and used far from the primary unit such that even if magnetic material is present, the inductance of the primary is not significantly changed.

In the proposed system, this is not the case:

- High permeability magnetic material is present in the secondary unit and is used in close proximity to the primary unit;
- One or more secondary units may be brought in close proximity to the primary unit simultaneously;

This has the effect of shifting the inductance of the primary significantly and also to different levels depending on the number of secondary units present on the pad. When the inductance of the primary unit is shifted, the capacitance required for the circuit to resonant at a particular frequency also changes. There are three methods for keeping the circuit at resonance:

- By means of a control system to dynamically change the operating frequency;
- By means of a control system to dynamically change the capacitance such that resonance is achieved at the predefined frequency;
- By means of a low Q system where the system remains in resonance over a range of inductances

The problem with changing the operating frequency is that the secondary units are typically configured to resonate at a predefined frequency. If the operating frequency changes, the secondary unit would be detuned. To overcome this problem, we can change the capacitance instead of the operating frequency. The secondary units can be designed such that each additional unit placed in proximity to the primary unit will shift the inductance to a quantised level such that an appropriate capacitor can be switched in to make the circuit resonate at a predetermined frequency. Because of this shift in resonant frequency, the number of devices on the

pad can be detected and the pad can also sense when something is brought near or taken away from the pad. If a magnetically permeable object other than a valid secondary unit is placed in the vicinity of the pad, it is unlikely to shift the system to the predefined quantised level. In such circumstances, the system could automatically detune and reduce the current flowing into the coil.

For a better understanding of the present invention and to show how it may be carried into effect, reference shall now be made, by way of example only, to the accompanying drawings, in which:

FIGURE 1 shows the magnetic design of typical prior art contact-less power transfer systems which require accurate alignment of the primary and secondary units;

FIGURE 2a shows the magnetic design of another typical prior art contact-less power transfer system which involves a large coil in the primary unit;

FIGURE 2b shows the non-uniform field distribution inside the large coil at 5mm distance from the plane of the coil, exhibiting a minimum in the centre;

FIGURE 3 shows a multiple-coil system where each coil is independently driven such that a localised field can be generated.

FIGURE 4a shows an embodiment of the proposed system which demonstrates a substantial departure from prior art with no secondary units present;

FIGURE 4b shows an embodiment of the proposed system with two secondary units present;

FIGURE 4c shows a cross section of the active area of the primary unit and the contour lines of the magnetic flux density generated by the conductors.

FIGURE 4e shows the magnetic circuit for this particular embodiment of the

proposed invention;

FIGURE 5 shows a schematic drawing of an embodiment of the primary unit and the secondary unit;

FIGURE 6a, 6b, 6c, 6d, 6e show some alternative embodiment designs for the magnetic unit or a component of the magnetic unit of the primary unit

FIGURES 7a and 7b show some embodiment designs for the magnetic unit of the secondary unit

FIGURES 8 shows the effect of flux guides. The thickness of the flux guide has been exaggerated for clarity;

FIGURE 8a shows that without flux guides, the field tends to fringe into the air directly above the active area;

FIGURE 8b shows the direction of current flow in the conductors in this particular embodiment;

FIGURE 8c shows that the flux is contained within the flux guides when magnetic material is placed on top of the active area;

FIGURE 8d shows a secondary unit on top of the primary unit;

FIGURE 8e shows a cross section of the primary unit without any secondary units

FIGURE 8f shows a cross section of the primary unit with a secondary unit on top and demonstrates the effect of using a secondary core with higher permeability than the flux guide.

FIGURE 9a shows a particular coil arrangement with a net instantaneous current flow shown by the direction of the arrow;

FIGURE 9b shows a similar coil arrangement to FIGURE 9a except rotated by 90 degrees;

FIGURE 9c shows the active area of the primary unit if the coil of FIGURE 9a is placed on top of FIGURE 9b. If the coil in FIGURE 9a is driven in quadrature to FIGURE 9b, the effect is a rotating magnetic dipole shown here.

Referring firstly to Figure 1, there is shown two examples of prior art contact-less power transfer systems which both require accurate alignment of a primary unit and a secondary unit. This embodiment is typically used in toothbrush or mobile phone chargers.

Figure 1a shows a primary magnetic unit **100** and a secondary magnetic unit **200**. On the primary side, a coil **110** is wound around a magnetic core **120** such as ferrite. Similarly, the secondary side consists of a coil **210** wound around another magnetic core **220**. In operation, an alternating current flows in to the primary coil **110** and generates lines of flux **1**. When a secondary magnetic unit **200** is placed such that it is axially aligned with the primary magnetic unit **100**, the flux **1** will couple from the primary into the secondary, inducing a voltage across the secondary coil **210**.

Figure 1b shows a split transformer. The primary magnetic unit **300** consists of a U-shaped core **320** with a coil **310** wound around it. When alternating current flows into the primary coil **310**, changing lines of flux is generated **1**. The secondary magnetic unit **400** consists of a second U-shaped core **420** with another coil **410** wound around it. When the secondary magnetic unit **400** is placed on the primary magnetic unit **300** such that the arms of the two U-shaped cores are in alignment, the flux will couple effectively into the core of the secondary **420** and induce voltage across the secondary coil **410**.

Figure 2a is another embodiment of prior art inductive systems typically used in powering radio frequency passive tags. The primary typically consists of a coil **510** covering a large area. Multiple secondary units **520** will have voltage induced in it when they are within the area encircled by the primary coil **510**. This system does not require the secondary coil **520** to be accurate aligned with the primary coil **510**. Figure 2b shows a graph of the magnitude of magnetic flux intensity across the area encircled by the primary coil **510** at 5mm above the plane of the primary coil. It shows a non-uniform field, which exhibits a minimum **530** at the centre of the primary coil **510**.

Figure 3 is another embodiment of prior art inductive system where by a multiple coil array is used. The primary magnetic unit **600** consists of an array of coils including **611, 612, 613**. The secondary magnetic unit **700** may consist of a coil **710**. When the secondary magnetic unit **700** is in proximity to some coils in the primary magnetic unit **600**, the coils **611, 612** are activated while other coils such as **613** remains inactive. The activated coils **611, 612** generate flux, some of which will couple into the secondary magnetic unit **700**.

Figure 4 shows an embodiment of the proposed invention. Figure 4a shows a primary coil **710** wound or printed in such a fashion that there is a net instantaneous current flow within the active area **740**. For example, if a dc current flows through the primary coil **710**, the conductors in the active area **740** would all have current flowing in the same direction. Current flowing through the primary coil **710** generates flux **1**. A layer of magnetic material **730** is present beneath the active area to provide a return path for the flux. Figure 4b shows the same primary magnetic unit as shown in Figure 4a with two secondary units **800** present. When the secondary units **800** are placed in the correct orientation on top of the active area **740** of the primary magnetic unit, the flux **1** would flow through the magnetic core of the secondary units **800** instead of flowing through the air. The flux **1** flowing through the secondary core would hence induce current in the secondary coil.

Figure 4c shows some contour lines for the flux density of the magnetic field

generated by the conductors **711** in the active area **740** of the primary magnetic unit **700**. There is a layer of magnetic material **730** beneath the conductors to provide a low impedance return path for the flux.

Figure 4e shows a cross-section of the active area **740** of the primary magnetic unit **700**. A possible path for the magnetic circuit is shown. The magnetic material **730** provides a low reluctance path for the circuit and also the magnetic core **820** of the secondary magnetic unit **800** also provides a low reluctance path. This minimizes the distance the flux has to travel through the air and hence minimizes leakage.

Figure 5 shows a schematic drawing of an embodiment of the whole system of the proposed invention. In this embodiment, the primary unit consists of a power supply **760**, a control unit **770**, a sensing unit **780** and a magnetic unit **700**. The power supply **760** converts the mains (or other sources of power) into a dc supply at an appropriate voltage for the system. The control unit **770** controls the driving unit **790** which drives the magnetic unit **700**. In this embodiment, the magnetic unit consists of two independently driven components, coil 1 and coil2, arranged such that the conductors in the active area of coil 1 would be perpendicular to the conductors in the active area of coil 2. When the primary unit is activated, the control unit causes a 90-degree phase shift between the alternating current that flows through coil 1 and coil 2. This creates a rotating magnetic dipole on the surface of the primary magnetic unit **700** such that a secondary unit would be able to receive power regardless of its rotational orientation (See Figure 9). In standby mode where no secondary units are present, the primary is detuned and current flow into the magnetic unit **700** is minimised. When a secondary unit is placed on top of the active area of the primary unit, the inductance of the primary magnetic unit **700** is changed. This brings the primary circuit into resonance and the current flow is maximised. When there are two secondary units present on the primary unit, the inductance is changed to yet another level and the primary circuit is again detuned. At this point, the control unit **770** uses feedback from the sensing unit **780** to switch another capacitor into the circuit such it is tuned again and current flow is maximised. In this embodiment, the secondary units are of a standard size and a

maximum of six standard-sized units can receive power from the primary unit simultaneously. Due to the standard-sizes of the secondary units, the change in inductance due to the change in secondary units in proximity is quantized to a number of predefined levels such that only a maximum of 6 capacitances is required to keep the system operating at resonance.

Figure 6 shows a number of different embodiments for the coil component of the primary magnetic unit. These embodiments may be implemented as the only coil component of the primary magnetic unit, in which case the rotation of the secondary unit is important to the power transfer. These embodiments may also be implemented in combination, not excluding embodiments which are not illustrated here. For example, two coils illustrated in figure 6a may be placed at 90 degrees to each other to form a single magnetic unit. In figures 6a to 6e, the active area **740** consists of a series of conductors with net current generally flowing in the same direction. In certain configurations, such as Figure 6c, there is no substantial linkage when the secondary unit is placed directly over the centre of the coil and hence power is not transferred. In figure 6d, there is no substantial linkage when the secondary unit is positioned in the gap between the two active areas **740**.

Figure 7a and 7b are embodiments of the proposed secondary magnetic units. A winding **810** is wound around a magnetic core **820**. Two of these may be combined in a single secondary unit, at right angles for example, such that the secondary unit is able to effectively couple with the primary unit at all rotations. These may also be combined with standard coils, as the ones shown in Figure 2a **520** to eliminate dead spots.

Figure 8 shows the effect of flux guides **750** positioned on top of the active area. The thickness of the material has been exaggerated for the sake of clarity but in reality would be in the order of millimetres thick. The flux guides **750** will minimize leakage and contain the flux at the expense of reducing the amount of flux coupled to the secondary unit. In Figure 8a, a primary magnetic unit is shown without flux guides **750**. The field will tend to fringe into the air directly above the active area.

With flux guides **750,** as shown in Figure 8b to 8f, the flux is contained within the plane of the material and leakage is minimised. In figure 8e, when there is no secondary unit **800** on top, the flux remains in the flux guide **750**. In figure 8f, when a secondary unit **800** is present with a relatively more permeable material as the core, part of the flux will flow via the secondary unit. The permeability of the flux guide **750** can be chosen such that it is higher than that of typical metals such as steel. When other materials such as steel, which are not part of secondary units **800**, are placed on top, most of the flux will remain in the flux guide **750** instead of travelling through the object. The flux guide **750** may not be a continuous layer of magnetic material but may have small air gaps in them to encourage more flux flow into the secondary unit **800** when it is present.

Figure 9 shows an embodiment of a primary magnetic unit whereby more than one coil is used. Figure 9a shows a coil **710** with an active area **740** with current flow parallel to the direction of the arrow **1**. Figure 9b shows a similar coil arranged at 90 degrees to the one in Figure 9a. When these two coils are placed on top of each other such that the active area **740** overlaps, the active area would look like the illustration in Figure 9c. Such an embodiment would allow the secondary unit to be at any rotation on top of the primary unit and couple effectively.

CLAIMS:

1. A system for transferring power without requiring direct electrical conductive contacts, the system comprising:

i) a primary unit having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to the plane of the surface within the active area; and

ii) at least one secondary unit including at least one conductor wound about a core;

wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in any orientation thereof substantially parallel to the surface of the primary unit in the active area, such that when the at least one secondary unit is placed on or in proximity to the active area in a predetermined orientation, the electromagnetic field induces a current in the at least one conductor of the at least one secondary unit.

2. A system as claimed in claim 1, wherein the primary unit includes a plurality of electrically-independent conductors configured so as to be able to generate a magnetic dipole that is switchable between different directions.

3. A system as claimed in claim 2, wherein the plurality of electrically-independent conductors is configured so as to be able to generate a rotating magnetic dipole in or substantially parallel to the laminar surface.

4. A system as claimed in any preceding claim, wherein the at least one electrically-independent conductor is substantially distributed and/or contained within the active area.

5. A system as claimed in any preceding claim, wherein the active area is provided with a substrate of a magnetic material.

6. A system as claimed in any preceding claim, wherein the primary unit includes at least one selectively operable capacitor adapted that a capacitance of a circuit including the at least one electrically-independent conductor and the at least one capacitor may be changed in response to a detected presence of one or more secondary units.

7. A system as claimed in any preceding claim, wherein the active area is provided with a flux guide having a relative permeability less than that of the core of the at least one secondary unit.

8. A primary unit device for transferring power in a non-conductive manner to at least one secondary unit including at least one conductor wound about a core, the primary unit device having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to a plane of the surface within the active area., and wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in any orientation thereof substantially parallel to the surface of the primary unit in the active area.

9. A device as claimed in claim 8, including a plurality of electrically-independent conductors configured so as to be able to generate a magnetic dipole that is switchable between different directions.

10. A device as claimed in claim 9, wherein the plurality of electrically-independent conductors is configured so as to be able to generate a rotating magnetic dipole in or substantially parallel to the laminar surface.

11. A device as claimed in any one of claims 8 to 10, wherein the at least one electrically-independent conductor is substantially distributed and/or contained within the active area.

12. A device as claimed in any one of claims 8 to 11, wherein the active area is provided with a substrate of a magnetic material.

13. A device as claimed in any one of claims 8 to 12, including at least one selectively operable capacitor adapted that a capacitance of a circuit including the at least one electrically-independent conductor and the at least one capacitor may be changed in response to a detected presence of one or more secondary units.

14. A device as claimed in any one of claims 8 to 13, wherein the active area is provided with a flux guide having a relative permeability less than that of the core of the at least one secondary unit.

15. A method of transferring power in a non-conductive manner from a primary unit to a secondary unit, the primary unit having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to the plane of the surface within the active area, and the secondary unit having at least one conductor wound about a core, wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in any orientation thereof substantially parallel to the surface of the primary unit within the active area and wherein flux lines of the electromagnetic field pass

through the core of the secondary unit when this is placed on or in proximity to the active area as a result of the core offering a path of least reluctance.

16. A method according to claim 15, wherein the primary unit includes a plurality of electrically-independent conductors which generate a magnetic dipole that is switchable between different directions.

17. A method according to claim 16, wherein the plurality of electrically-independent conductors generate a rotating magnetic dipole in or substantially parallel to the laminar surface.

18. A method according to any one of claims 15 to 17, wherein the at least one electrically-independent conductor is substantially distributed and/or contained within the active area.

19. A method according to any one of claims 15 to 18, wherein the active area is provided with a substrate of a magnetic material and wherein the magnetic material completes a magnetic circuit.

20. A method according to any one of claims 15 to 19, wherein the primary unit includes at least one capacitor that is switched in or out such that a capacitance of a circuit including the at least one electrically-independent conductor and the at least one capacitor may be changed in response to a detected presence of one or more secondary units.

21. A method according to any one of claims 15 to 20, wherein the active area is provided with a flux guide having a relative permeability less than that of the core of the at least one secondary unit.

22. A secondary unit for use with the system, device or method of any one of the preceding claims, the secondary unit including at least one conductor wound about a core and having a substantially flat form factor.

23. A secondary unit as claimed in claim 22, having a core thickness of 2mm or less.

24. A secondary unit as claimed in claim 23, having a core thickness of 1mm or less.

25. A secondary unit as claimed in any one of claims 22 to 24, wherein the core is made of an amorphous metallic material.

26. A system for transferring power, substantially as hereinbefore described with reference to Figures 4 to 9 of the accompanying drawings.

27. A primary unit device for transferring power, substantially as hereinbefore described with reference to Figures 4 to 9 of the accompanying drawings.

27. A method of transferring power, substantially as hereinbefore desctibed with reference to Figures 4 to 9 of the accompanying drawings.

ABSTRACT

IMPROVEMENTS RELATING TO CONTACTLESS POWER TRANSFER

There is disclosed a system and method for transferring power without requiring direct electrical conductive contacts. There is provided a primary unit having a power supply and a substantially laminar surface having at least one electrically-independent conductor that generates an electromagnetic field when a current flows therethrough and having an active area defined within a perimeter of the surface, the at least one conductor being arranged such that electromagnetic field lines generated by the at least one conductor are substantially parallel to the plane of the surface within the active area; and at least one secondary unit including at least one conductor wound about a core; wherein the active area has a perimeter large enough to surround the core of the at least one secondary unit in any orientation thereof substantially parallel to the surface of the primary unit in the active area, such that when the at least one secondary unit is placed on or in proximity to the active area in a predetermined orientation, the electromagnetic field induces a current in the at least one conductor of the at least one secondary unit.

P100245gb.spc

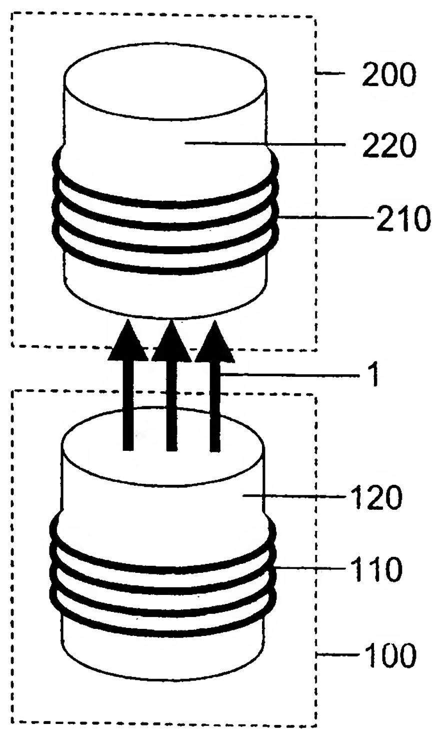

Figure 1a
(Prior Art)

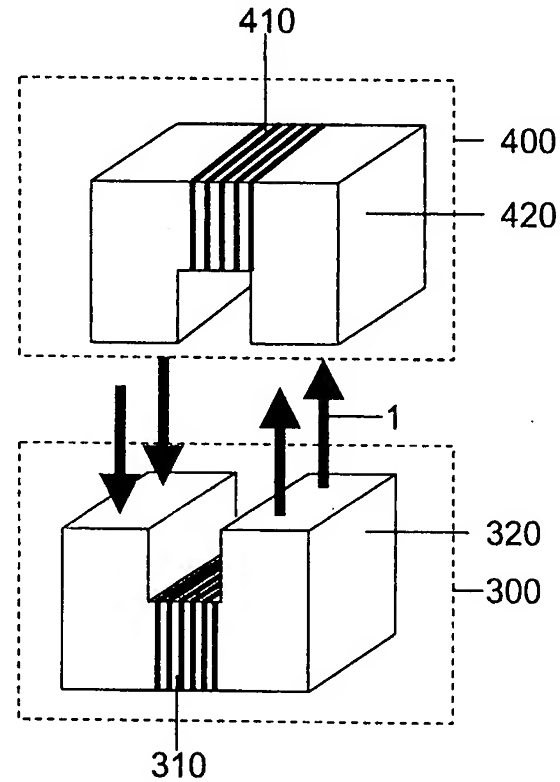

Figure 1b
(Prior Art)

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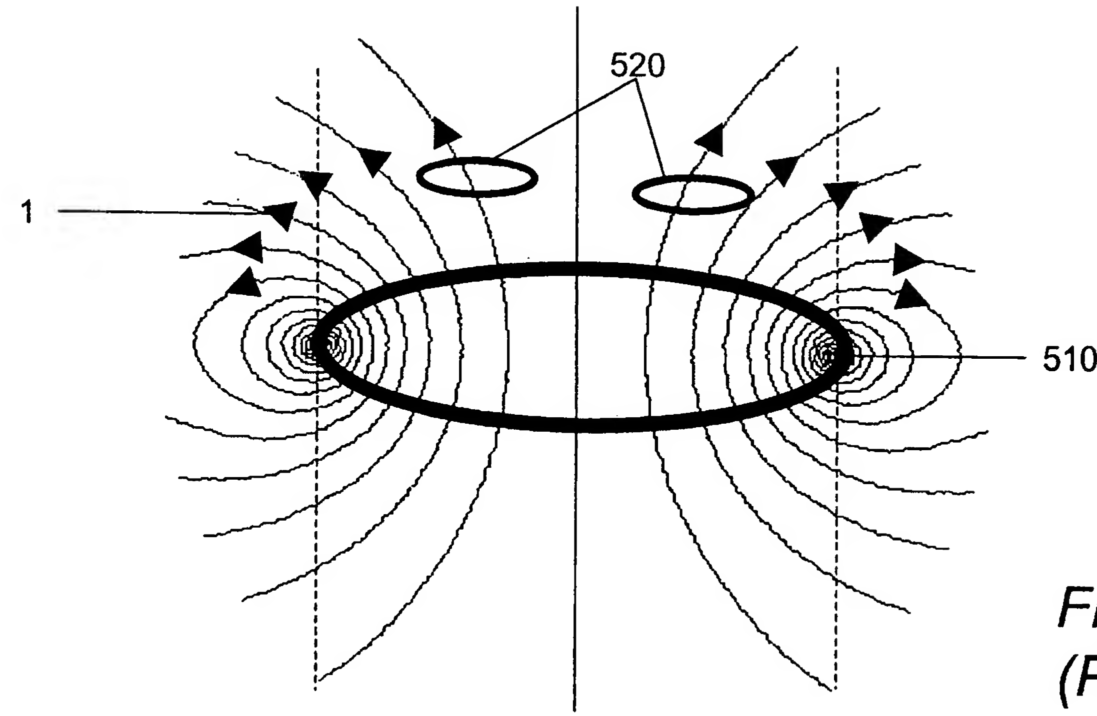

Figure 2a
(Prior Art)

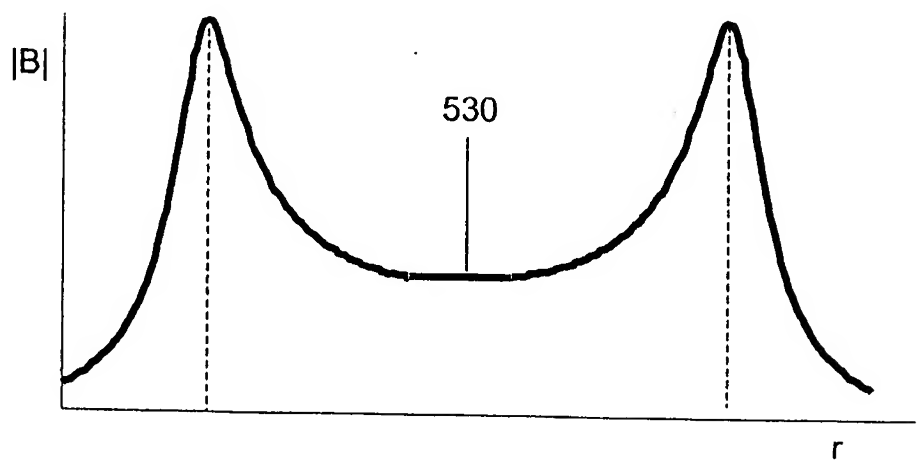

Figure 2b

X =5mm

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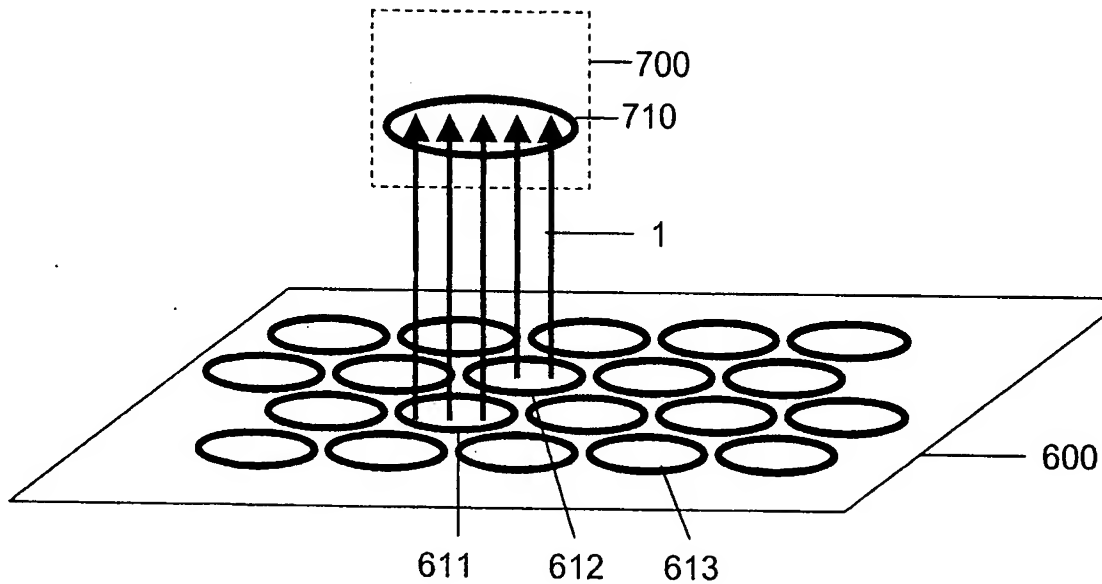

Figure 3

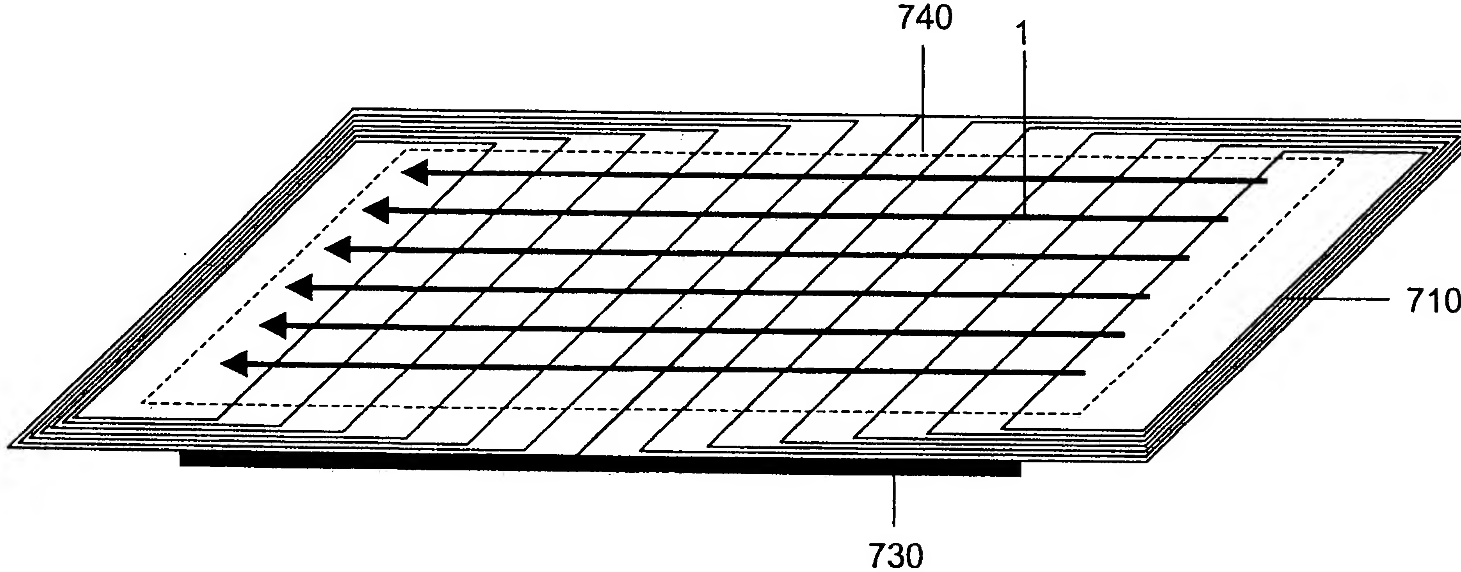

Figure 4a

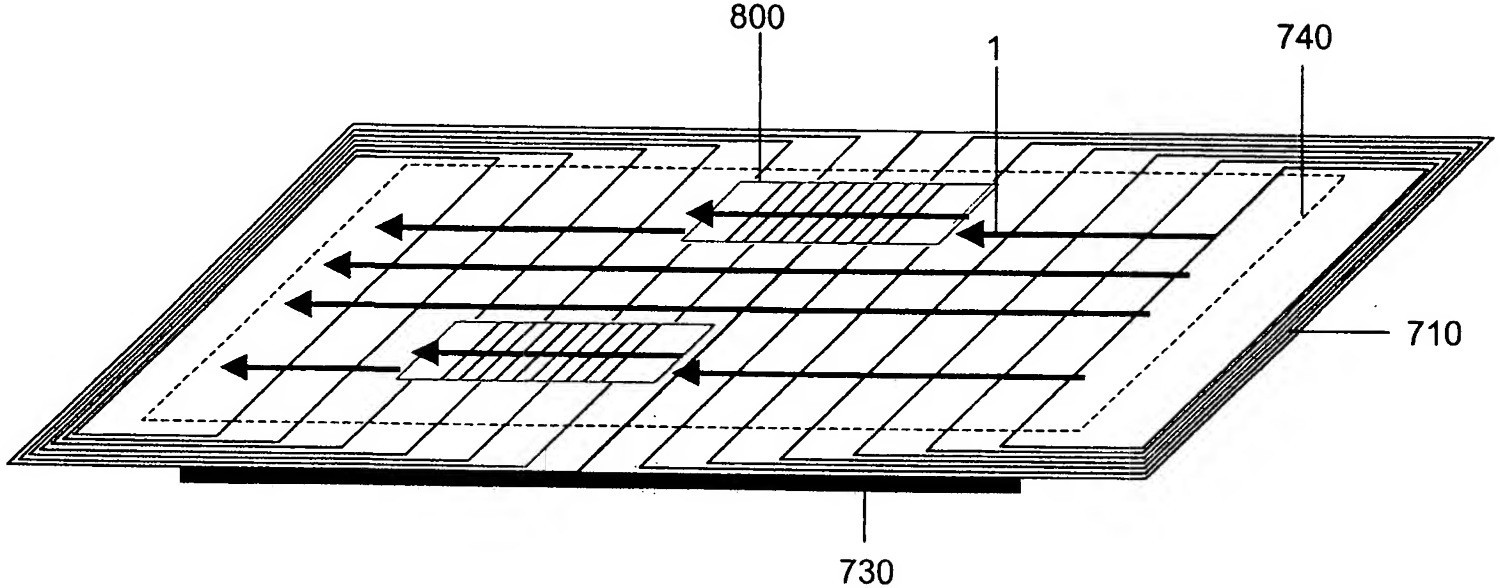

Figure 4b

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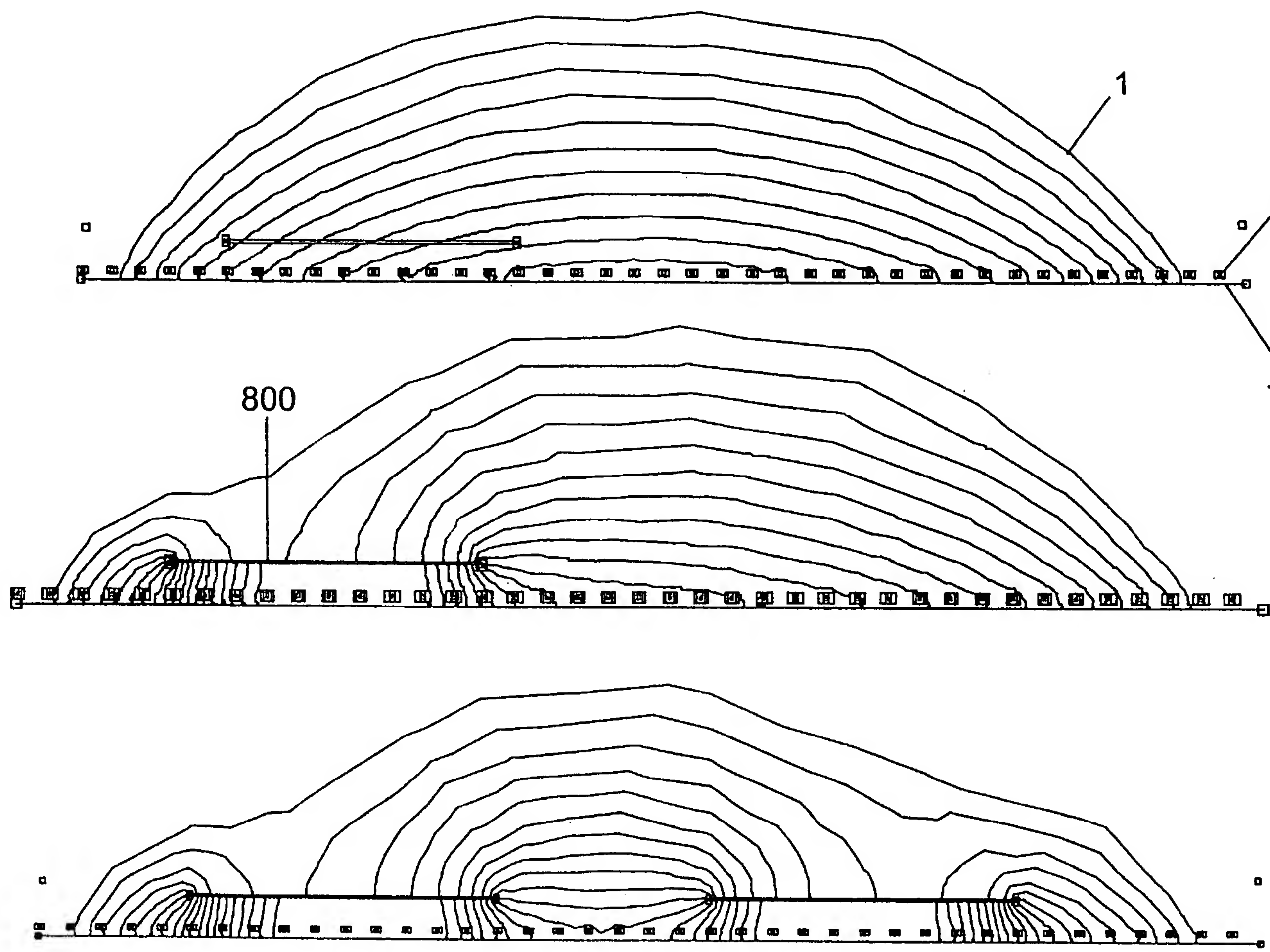

Figure 4c

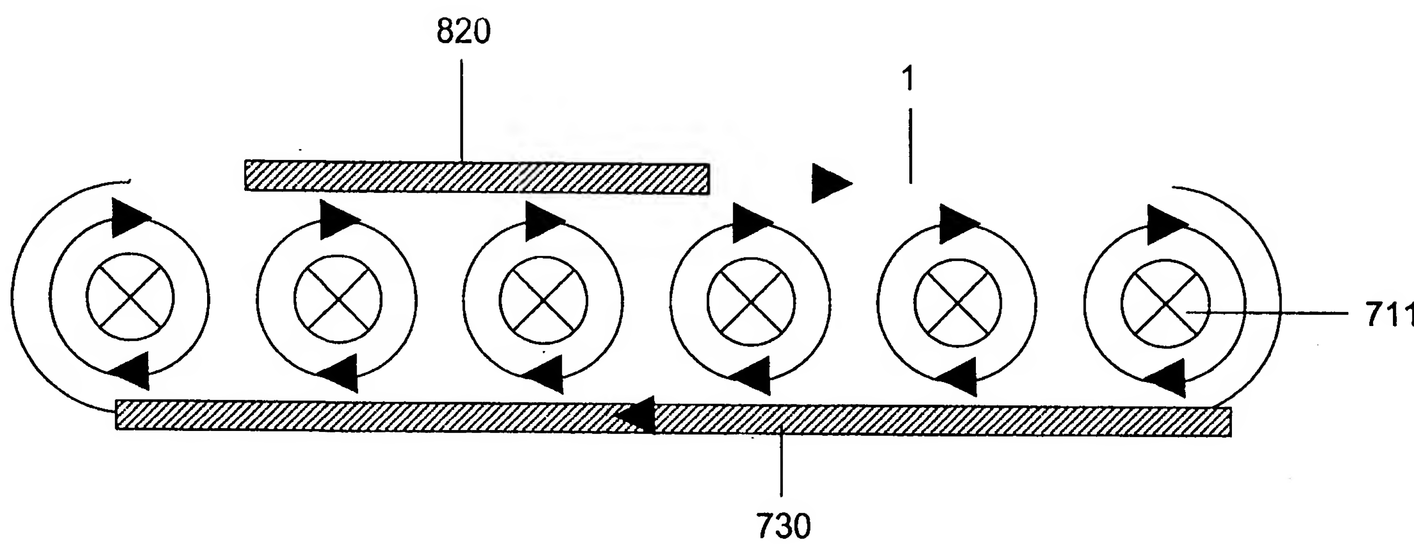

Figure 4e

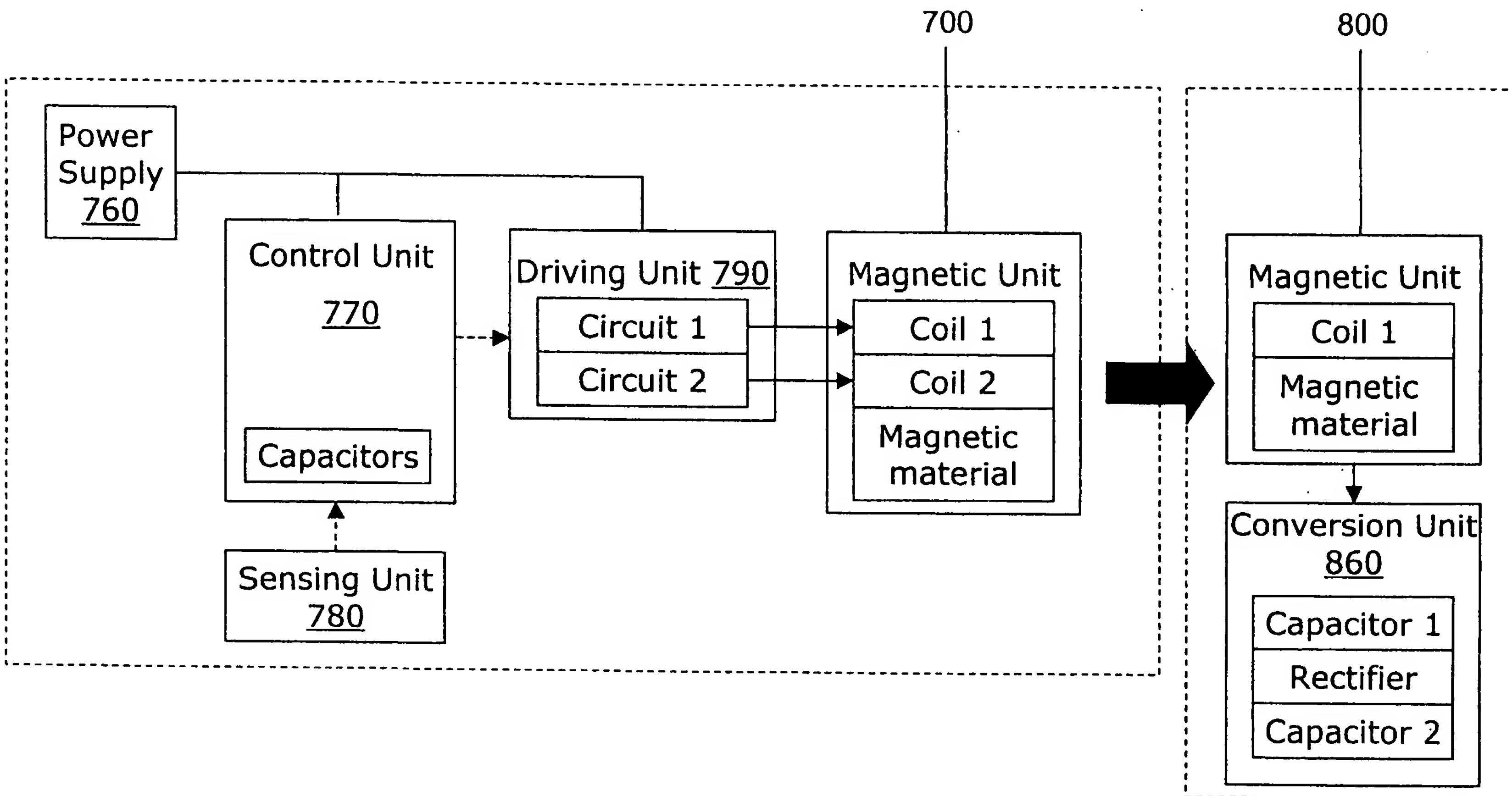
700
800
Power Supply 760
Control Unit 770
Capacitors
Sensing Unit 780
Driving Unit 790
Circuit 1
Circuit 2
Magnetic Unit
Coil 1
Coil 2
Magnetic material
Magnetic Unit
Coil 1
Magnetic material
Conversion Unit 860
Capacitor 1
Rectifier
Capacitor 2

Figure 5

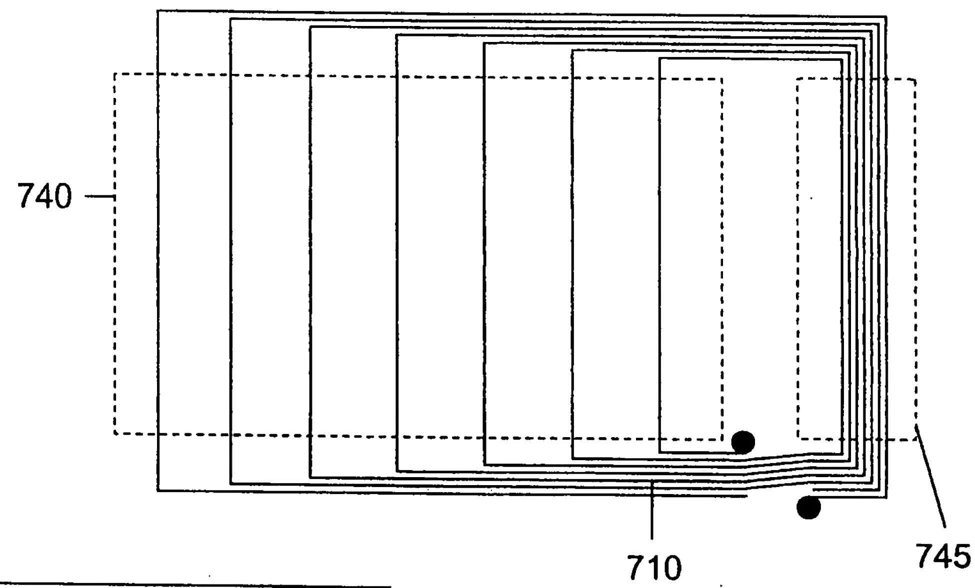

Figure 6a

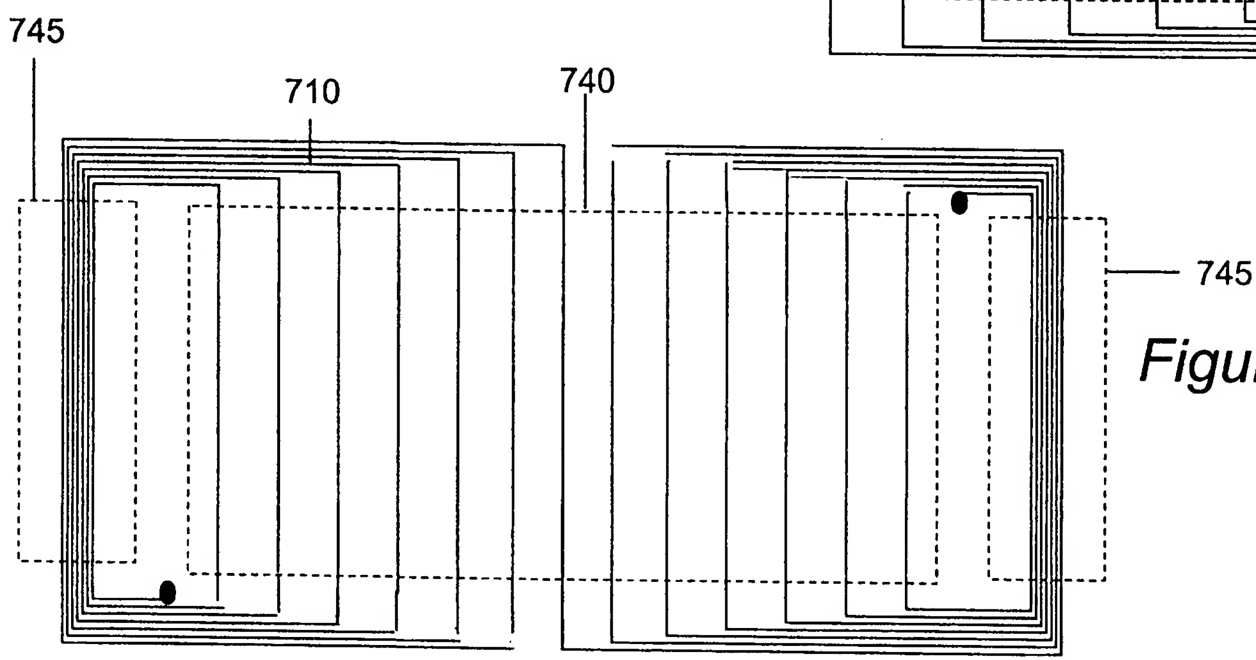

Figure 6b

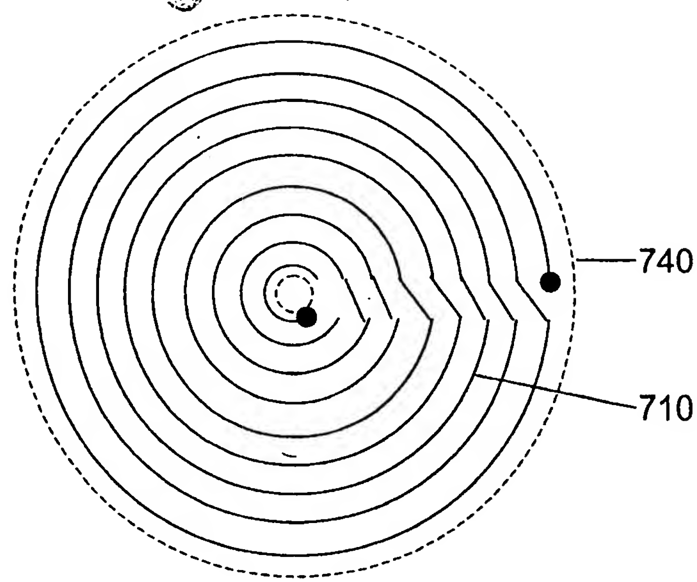

Figure 6c

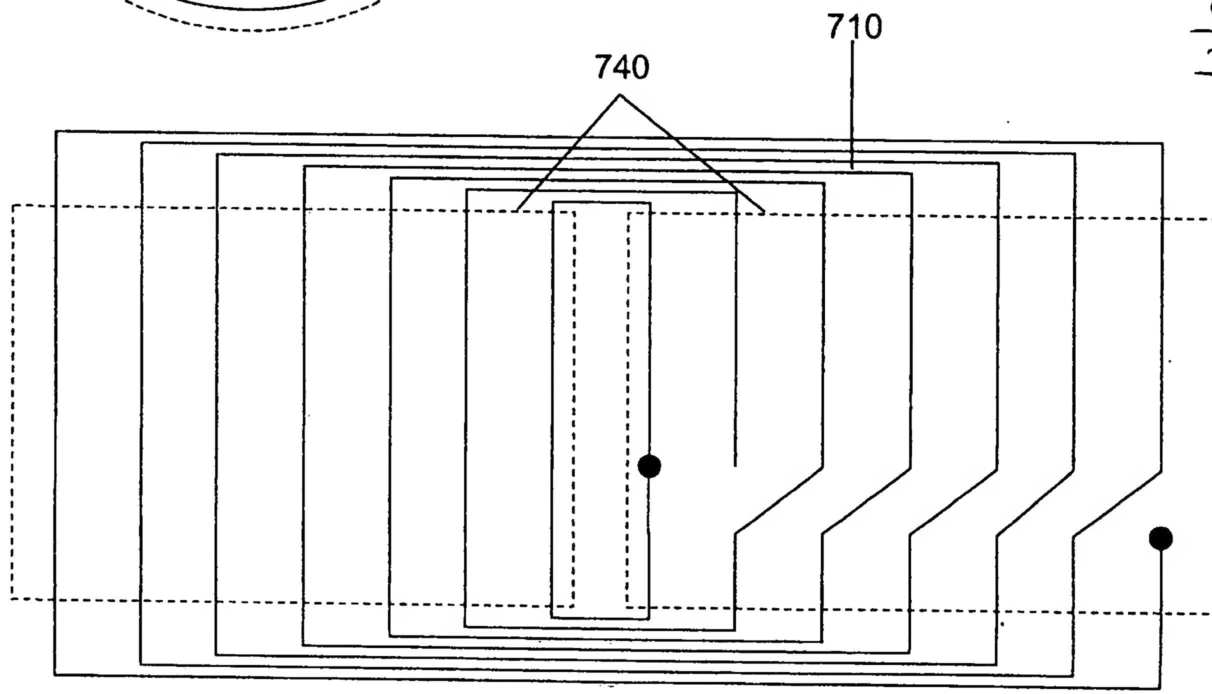

Figure 6d

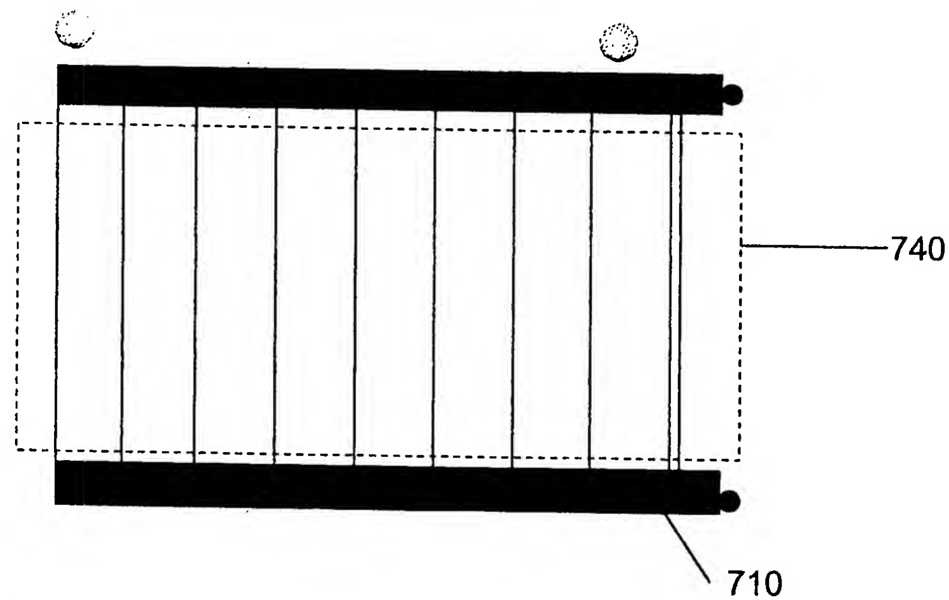

Figure 6e

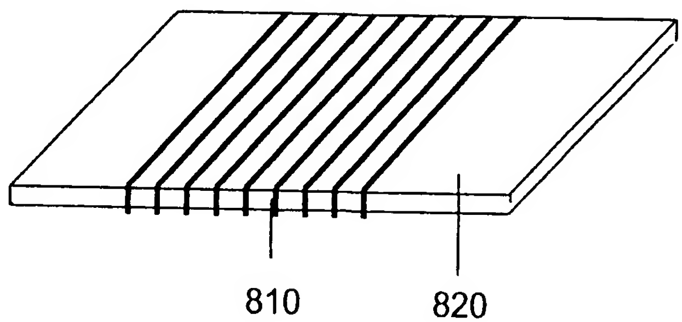

Figure 7a

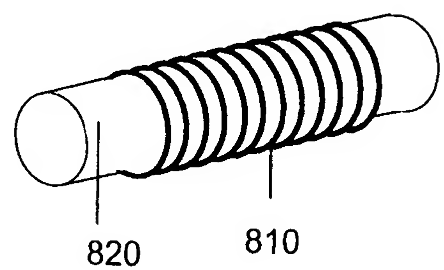

Figure 7b

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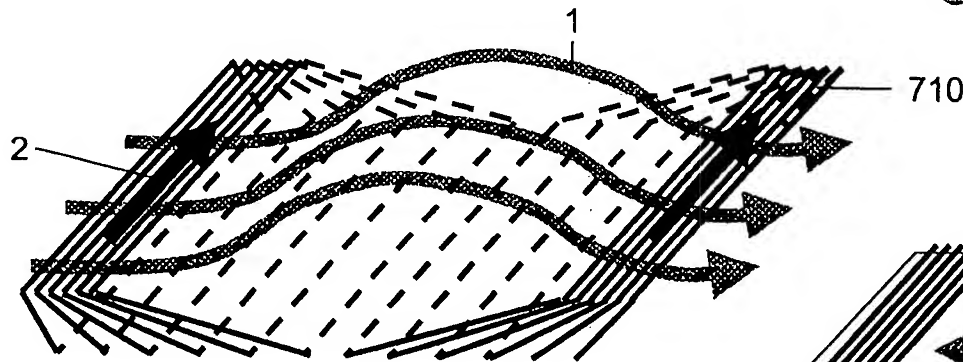

Figure 8a

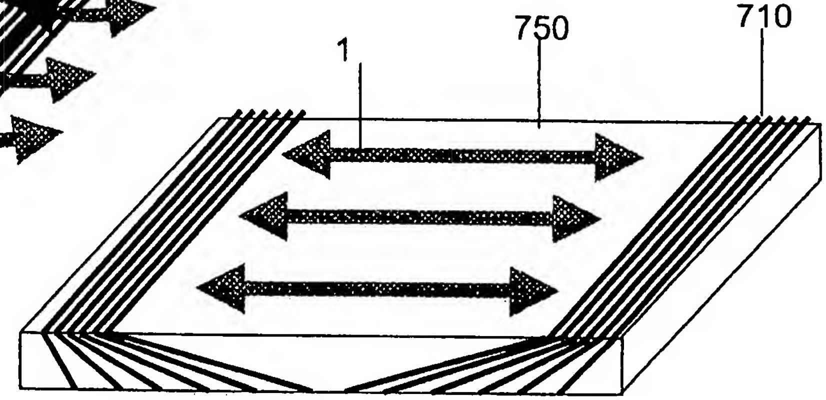

Figure 8c

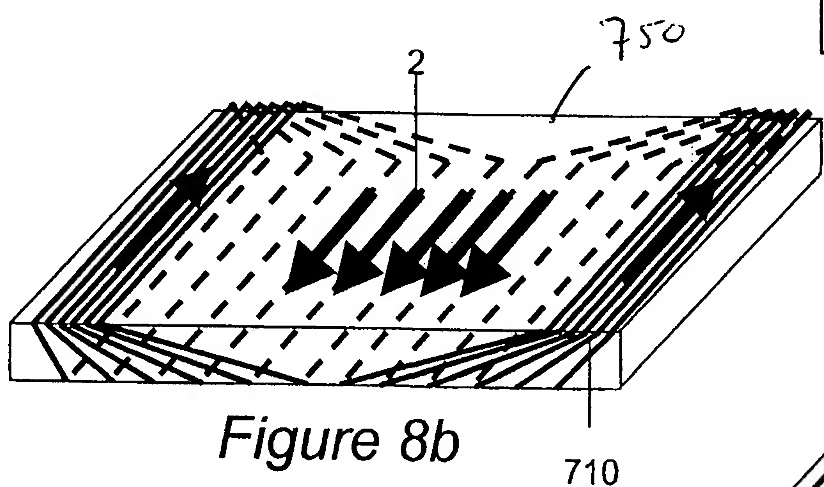

Figure 8b

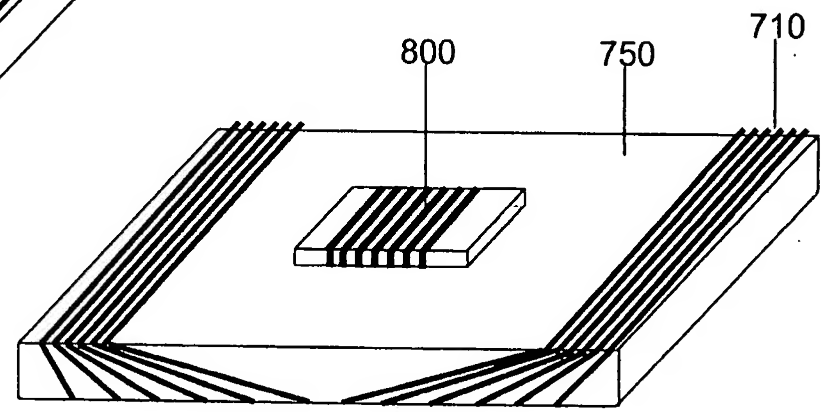

Figure 8d

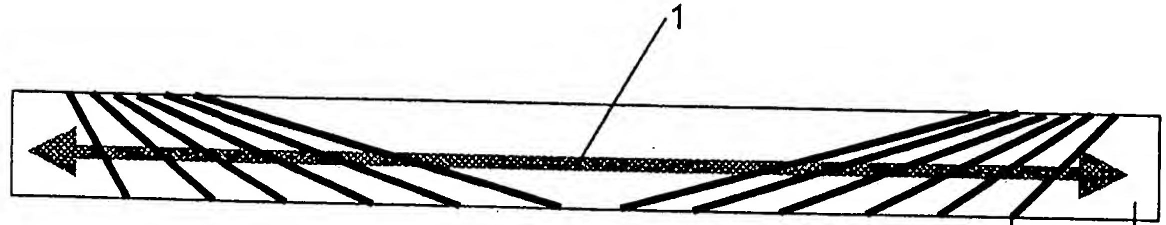

Figure 8e

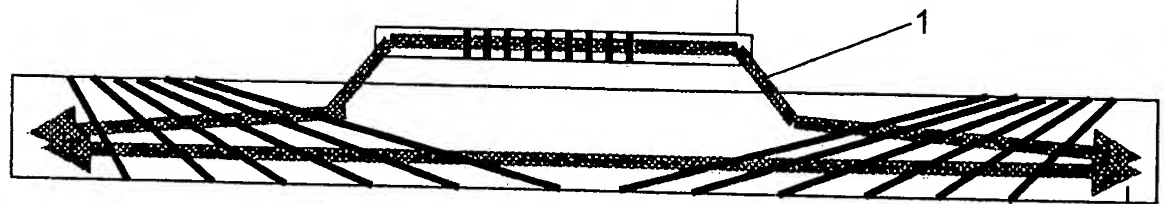

Figure 8f

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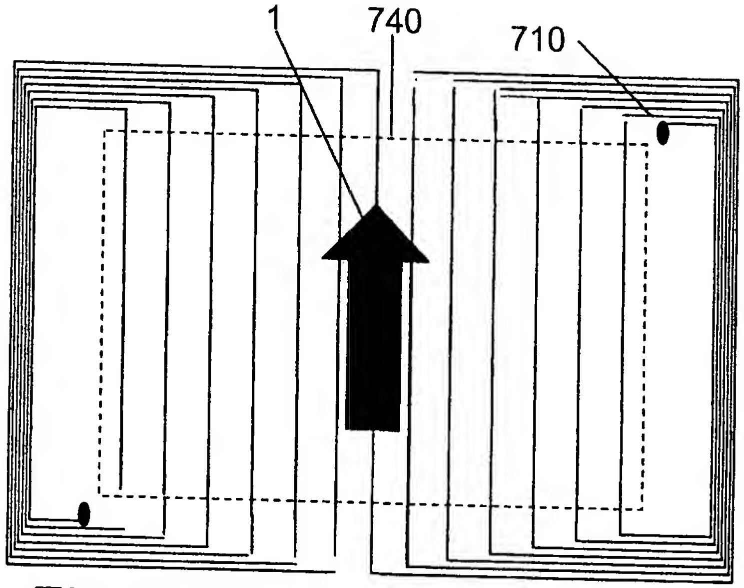

Figure 9a

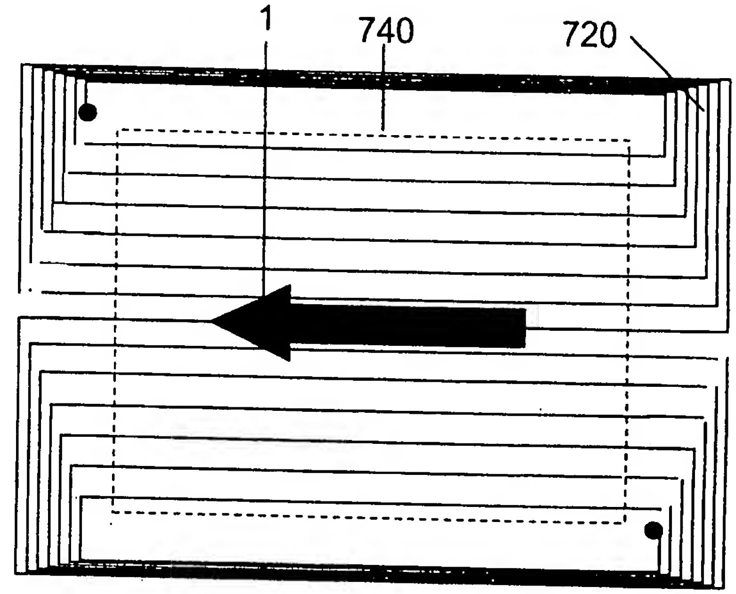

Figure 9b

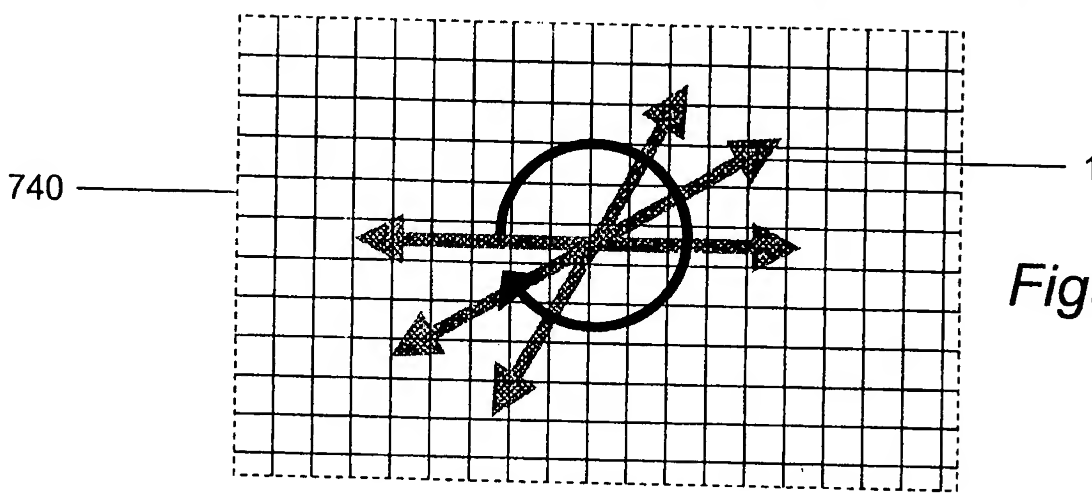

Figure 9c